Impact of low-frequency p modes on the inversions of the internal rotation of the Sun

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Abstract. We used the m-averaged spectrum technique ("collapsogram") to extract the low-frequency solar p-mode parameters of low- and intermediate-angular degrees ($l \leq 35$) in long time series of GONG and MDI observations. Rotational splittings and central frequencies have been measured down to $\approx 850\,\mu$Hz, including predicted modes which have not been measured previously. Both GONG and MDI frequency splitting data sets were numerically inverted to extract the internal solar rotation rate. The impact of the very low-frequency observables and the differences between GONG and MDI data sets on the inversion results are also analyzed.

1. Measurements of low-frequency p modes of low- and medium-angular degrees ($1 \leq l \leq 35$)

In the search of low-frequency acoustic modes, the usual peak-fitting methods, using individual-m spectra, are naturally limited by the decreasing signal-to-noise ratio (SNR). Instead, several pattern-recognition techniques have been developed in an effort to reveal the presence of the modes in the low-frequency range. We use here an adaptation of the rotation-corrected m-averaged spectrum technique which finds the best set of the a-coefficient splittings yielding the narrowest profile in the average spectrum (Salabert, Leibacher, & Appourchaux 2007). Before averaging, each m-spectrum at a given (n, l) is shifted by a frequency that compensates for the effect of differential rotation and non-spherical effects on the frequencies. A high SNR can result from combining individual low-SNR individual-m spectra, none of which would yield a strong enough peak to measure (Fig. 1). This method, called collapsogram, has been applied to 3960 days of GONG data and to 2088-day coeval observations of GONG and MDI for modes with $1 \leq l \leq 35$. Acoustic modes down to $\approx 850\mu$Hz have been observed (Fig. 2) and their parameters estimated by fitting the rotation-corrected m-averaged spectrum with an asymmetric Lorentzian profile.
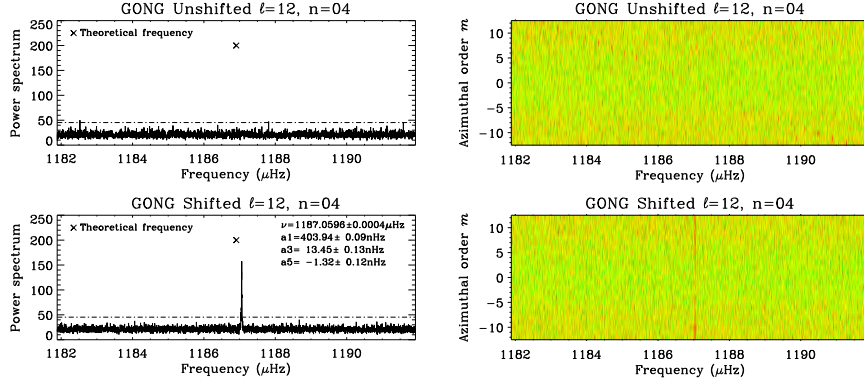
Figure 1. Collaspograms for $l = 12, n = 4$, and their $m - \nu$ diagrams before and after shifting in frequency by the indicated estimates of the a-coefficients.

2. Rotational inversions of the GONG and MDI low-frequency p modes measured using the collapsograms

Rotational inversions were computed using the a-coefficients of the low-frequency p modes of low- and intermediate-angular degrees measured with the collapsograms in long times series of GONG and MDI observations (Fig. 3). The inversions were carried out using an iterative method implemented to avoid the need to invert matrices (recalling the ill-posed nature of the inversion problem). For details about the inversion methodology, see Eff-Darwich & Korzennik (these proceedings). Only modes with $l \leq 35$ and $\nu \leq 2100$ μHz were used. The inversions of both MDI and GONG data sets give consistent results and no significant differences are found when inverting 2088 days or 3960 days of data. Since observational uncertainties are reduced by a factor proportional to the squared root of the number of days, it will be necessary to have extremely long series to find significant improvements in the rotational distribution. Figure 4 shows the rotational inversion of the low-frequency modes measured with the collapsograms combined with the mean of 35×108-day GONG PEAKFIND data (using both the higher-degree and higher-frequency modes from PEAKFIND).

3. Comparisons between the collapsograms and other measurements

Figure 5 shows the comparisons between the rotational inversions using the a-coefficients obtained with the collapsograms and those measured by Korzennik (2005) fitting the individual-m spectra. In both methods, the same coeval 2088 days of observations have been used. The effect of the differences in the low-frequency ($\nu \leq 2100$ μHz) and low-degree ($l \leq 35$) splitting data sets between Korzennik (2005) and the ones obtained using the collapsograms are translated to the internal rotational profiles. Special care should be taken regarding the calculation of the observational errors when only Clebsch-Gordan coefficients are available (Eff-Darwich & Korzennik, these proceedings). Small differences in the data sets result in the observed large discrepancies in the radiative zone at high latitude, due to a lack of sensitivity in these regions (right panel of Fig. 5).
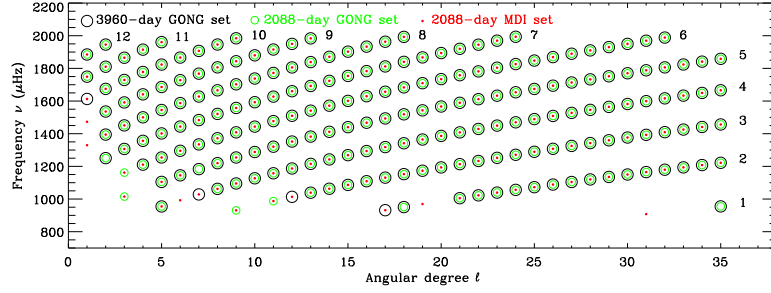
Figure 2. $l - \nu$ diagram of the low-frequency modes ($l \leq 35$) observed with the collapsograms in 3960 days of GONG observations (black) and 2088 coeval days of GONG (green) and MDI (red) observations. The ridges of same radial order are also indicated from $n = 1$ to $n = 12$.
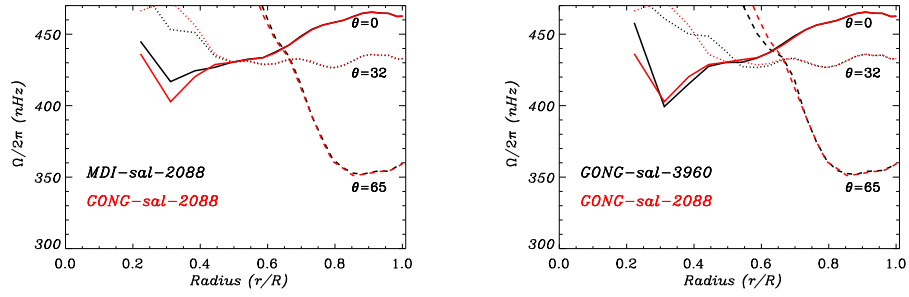

Figure 3. Rotational inversions of the low-frequency p modes with $l \leq 35$ measured using the collapsograms for 2088-day GONG and MDI data sets (left panel), and 2088-day and 3960-day GONG data sets (right panel).
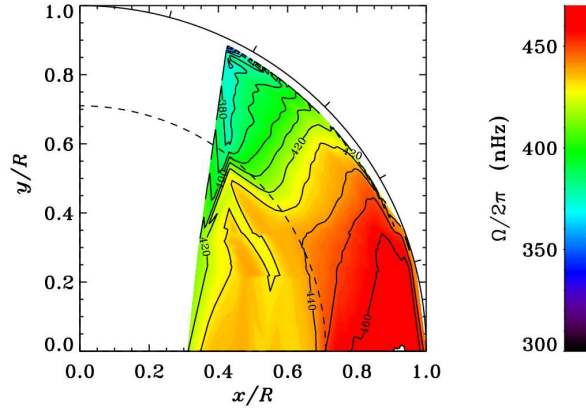

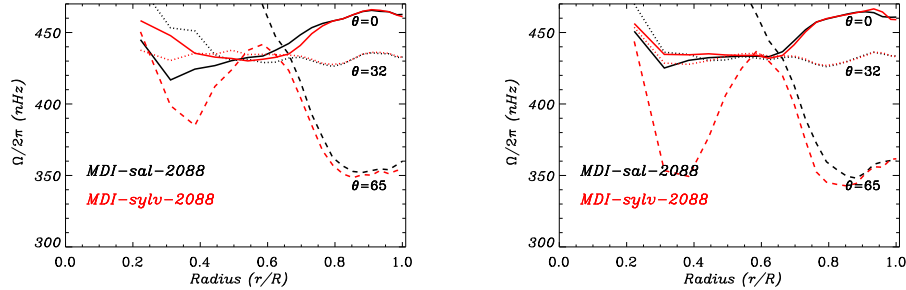Figure 4. Inversion of the 3960-day GONG data set combined with the mean of 35×108-day GONG PEAKFIND data.

Figure 5. Rotational inversions of the MDI 2088-day data sets of p modes with $l \leq 35$ and $\nu \leq 2100$ μHz obtained using the collapsograms and by Korzennik (2005) (left panel). Same as left panel but complemented with the higher-degree and higher-frequency p modes from Korzennik (2005) (right panel).

4. Conclusions

We performed rotational inversions by using the a-coefficients of the low-frequency solar p modes of low- and intermediate-angular degrees ($1 \leq l \leq 35$) measured in long time series of GONG and MDI observations with the m-averaged spectrum technique (also called collapsogram, Salabert et al. 2007). We showed that the inversions of both GONG and MDI data sets give consistent results and that no significant differences are found when inverting 2088 days or 3960 days of data. We also compared with the rotational inversions obtained by using the a-coefficients measured by Korzennik (2005) fitting the individual-m spectra and stressed out the importance on how the observational errors are calculated.

References

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